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RESEARCH PAPER

Effects of Wheeled Cable Skidding on Residual Trees in Selective Logging in Caspian Forests

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Abstract There are increasing demands on silvicultural practices to reduce the adverse impacts of harvesting. Damage to residual trees caused by ground-based skidding was assessed in stands with low [3.4 stems per hectare (sph), 14.36 m^3/ha], medium (5.2 sph, 21.61 m^3/ha), and high (7.1 sph, 25.95 m^3/ha) harvest intensities. Skidding was conducted using a cable skidder. After the skidding operation, a field survey was conducted to collect data on all residual trees (species, dbh, height) and on tree wounds (size class, location, intensity of damage). It was hypothesized that increased harvest intensity leads to increased injury rates. The treatment with the highest harvest intensity was found to cause the highest percentage of damage and the largest stem wounds. The most common types of damage were stem wounds to the cambium layer and bark scrapes. In all three harvest intensity treatments the probability of individual tree damage decreased as skid-trail cross slope decreased and distance to skid-trail edge increased. It is concluded that harvesting intensity should be limited to 5 trees/ha during each harvesting operation to reduce extent of tree damage and thus future financial loss.

Keywords Residual trees · Damage probability · Ground-based skidding · Harvest intensity · Stem wounds

Introduction

Forest ecosystems are multifunctional, fulfilling various functions of environmental protection including water and air quality, prevention of erosion, CO_2 sequestration and biodiversity conservation and well as providing recreation services (Fuhrer

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2000). Forest management affects forest ecosystem functions and services (Klenner et al. 2009). Therefore, there is an increasing demand for improvement in the quality of forest management to maintain forest multi-functionality (Higman et al. 2005) and preserve the various non-timber goods and services from which human welfare benefits (Fjeld and Granhus 1996).

Obviously, some residual stems will be damaged when forest harvesting takes place (Lamson et al. 1985). Physical damage to tree roots and boles can result in loss of vigour and reduce the tree growth that may have arisen from reduced competition (Shigo 1979). Damage to residual trees also can reduce timber value because of the volume loss caused by wood discoloration or decay. The size and severity of wounds, time since injury and species which are damaged are directly correlated with the tree decay (Shigo 1979). Further, damaged trees are more susceptible to radial and ring shakes (Fajvan et al. 2002) and mechanical tree injuries increase the biotic risk.

The sizes of tree injuries depend on the harvesting method and intensity as well as on the type of machinery used (Jactel et al. 2009). Heavy harvesting machines for example result in mechanical injuries to roots in the upper soil layers which can stimulate the spread of Armillaria root disease (Zolciak and Sierota 1997). Smith et al. (1994) showed that sapwood wounds pose no immediate threat to trees but increase the likelihood of attack by insects or diseases. Logging damage to the residual trees is a consequence of any harvesting operation (Froese and Han 2006). The frequency and extent of decay depend on the area, width, depth and location of wounds, and on tree species, age and vigour (Froese and Han 2006). During the skidding operation, reducing the damage to residual trees is important to maintain stand vigour and timber quality (Fajvan et al. 2002).

There is some indication from previous studies that logging impacts depend on the type and intensity of forest management operations. Fajvan et al. (2002) stated that trees of the minimum diameter limit of 12 inches have a higher percentage of damage and larger stem wounds than trees of 16 inch diameter in shelter-wood cutting in the Appalachian forest. The intensity of timber extraction, measured as trees harvested per hectare, might have consequences for some forest functions, including biodiversity maintenance, carbon sequestration and producing subsequent timber crops, as shown by Panifil and Gullison (1998) in Bolivia. Other researchers, however, have found that the occurrence of logging wounds is independent of harvest intensity (e.g. Nyland and Gabriel 1971; Reisinger and Pope 1991). Moreover, storm damage might be correlated with the skills and attitude of the logging contractor and machine operator (Reisinger and Pope 1991; Smith et al. 1994), the season of harvest (Aho et al. 1983) and site variables (Cline et al. 1991).

In Iran, small-scale forest management through selective logging occurs only in the Caspian forests. Single and group tree selection is practiced almost throughout the Caspian forests. Because of the higher initial costs of harvesting machines, the large tree diameter and expansive crowns of hardwoods and the moderately steep terrain in the Caspian forests, use of chainsaws and wheeled cable skidders is still the most common harvesting system (Behjou et al. 2008). Spinelli et al. (2010) studied the impact of traditional small-scale logging systems using tracked and rubber-tyred farm tractors in Mediterranean forestry, finding that 12–14 % of the

residual trees are usually damaged during conventional harvesting. Until now, no study has measured the impact of harvest intensity on residual stand trees in Caspian forests.

This study examined the extent of injury to the residual stand by the ground-based skidding system under varying harvest intensities in a Caspian hardwood forest of northern Iran. Harvest impacts on three alternative harvest intensities and three stand densities were compared. It is hypothesized that increasing harvest intensity leads to increased injury rates.

The Study Sites

The study was conducted in Shafaroud forest, Guilan province, northern Iran (Fig. 1) in April 2009. The overstorey canopy basal area was dominated by *Fagus orientalis* (beech), *Carpinus* sp. (hornbeam), *Acer* sp. (maple) and *Alnus subcordata* (alder). The elevation was approximately 1,250 m above sea level and the orientation north-facing. The average annual rainfall was 1,050 mm, and the average temperature 18 °C. Three study sites under small-scale forestry were selected (compartments 228, 231, 232; Fig. 1). Each study site was divided into three treatment blocks. In the Caspian forests the compartment numbering system is designed to help in forest planning and management. The silviculture treatment was a form of selective logging. Each treatment block included all three harvest intensity treatments: low intensity (3.4 spi harvested), medium intensity (5.2 spi), and high intensity (7.1 spi), and there were three replicates of each harvest intensity treatment. Table 1 shows the characteristics of study sites after skidding of 1,642 m^3 (822 trees) of timber including 410 m^3 (214 trees) in compartment 228, 670 m^3 (357 trees) in compartment 231, and 562 m^3 (251 trees) in compartment 232. Tree injuries were assessed immediately after harvesting.

Research Method

To assess the damage to residual trees a 100 % enumeration was conducted along the skid trails after ground-based skidding. Damage assessment procedures were based on methods used in previous studies (e.g. Fairweather 1991; Nichols et al. 1994; Fajvan et al. 2002; Jackson et al. 2002; Krueger 2004). All damaged trees greater than 10 cm in diameter at breast height (dbh) from 2 m left and right on the edges of skid trails were labeled and the types of damage were recorded. Tree damage was classified as severe, moderate or minor. Damage to residual trees was recorded according to the location and severity of wounds (Table 2).

Each stem and root wound of injured trees was categorized by the intensity of damage andlocation on the stem. Wound severity was classified as either a scuff (bark scraped but intact), a scrape (bark scraped off and wood exposed), or a gouge (lacerated exposed wood). Combination wounds such as a scrape within a scuff were noted and each type measured separately. The distance from residual trees to the nearest skid trail was measured from the middle of the tree stem to the closest

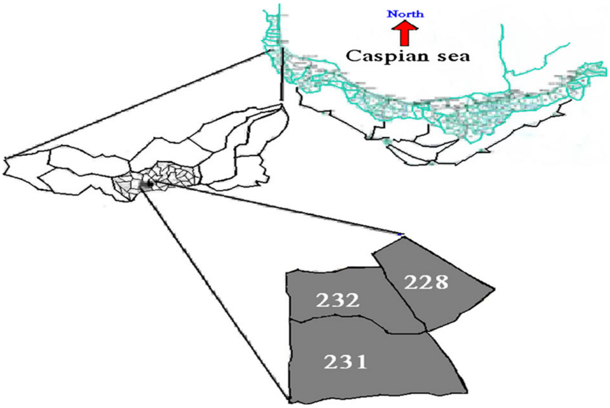

Fig. 1 Location of study region (*upper right*), area (Shafaroud forests, *left*) and sites (compartments 228, 231, 232 *bottoms*) in northern Iran

tyre track of a primary, secondary or tertiary skid trail. On primary skid trails, more than 10 trees, in secondary skid trails 2–10 trees, and in tertiary skid trails one tree had been skidded. The skid trails were classified as primary, secondary and tertiary. The heavier traffic over primary skid trails made these wider than secondary and tertiary skid trails.

Data Analysis

Analysis of covariance (ANCOVA) was used to examine differences in residual stand structure (basal area, trees per hectare and stand diameter) among treatments. To explain a treatment difference that may result from differences in pre-harvest stand density, an ANCOVA was initially performed (Table 1).

Inclusion of the variable 'pre-harvest basal area' did not significantly improve the ANCOVA model, and therefore a randomized block ANOVA was used to determine treatment differences in wound size. Dependent variables included total area damaged per tree (cm^2) and ratio of wound width of tree circumference (wound–stem ratio). The wound–stem ratio was used because a similar-sized wound will have a greater impact on a small tree than on a large tree (Fajvan et al. 2002). Because the assumption of normality of the wound size and wound–stem data was not satisfied, wound size and wound–stem ratio values were transformed to logarithms (to the base 10) and basal areas were square root transformed. Logistic regression was used to develop a probability model for estimating the occurrence of residual stem damage based on pre-harvest and post-harvest tree, stand and harvest attributes. The outcome of damage to each stem is binary (damaged or undamaged). The stepwise logistic regression procedure in the SAS statistical software package (described by Littell et al. 1991) was used to develop the final damage model. The probability of a tree being damaged during harvest is expressed as a continuous function in the logistic model:

Table 1 Characteristics of the study sites and harvesting treatments

Com. no.	Harvesting volume (m3)	Treatment	Stand density (trees/ha)	N of harvested trees	Area (ha)	Harvest intensity (trees/ha)	Species composition of harvested trees
228	410	1 (low intensity)	164	51	15	3.4	Beech (95), Alder (81), Hornbeam (33), Maple (5)
		2 (medium intensity)	169	78	15	5.2	
		3 (high intensity)	173	85	12	7.1	
231	670	1 (low intensity)	171	68	20	3.4	Beech (133), Alder (79), Maple (13), Hornbeam (23), Ash (3)
		2 (medium intensity)	161	104	20	5.2	
		3 (high intensity)	176	185	26	7.1	
232	562	1 (low intensity)	168	51	15	3.4	Beech (272), Alder (76), Maple (9)
		2 (medium intensity)	176	94	18	5.2	
		3 (high intensity)	164	106	15	7.1	

Table 2 Classification of damage sustained by residual trees along skid trails

Damage level	Stem	Root
Severe	Snapped at base, bent, or severely leaning	Uprooted
Moderate	Exposed and damaged cambial tissue	Exposed and damaged cambial tissue
Minor	Exposed but undamaged cambial tissue, bark scrape	Exposed cambial but no damage, root scrape

$$P\ (Y_i = 1) = [1 + \exp(-(B_0 + B_1X_1 + B_2X_2 + \cdots + B_nX_n))] - 1$$

where P is the probability of damage ($Y_i = 1$ if undamaged, 0 if damaged); the B_i represent estimated regression parameters, and the X_i represents the independent variables influencing residual tree damage. The following independent variables were considered to develop the model: land slope, tree dbh, stand density (pre-harvest and post-harvest trees per hectare), basal area per hectare, harvest intensity (number of trees harvested per hectare), and distance of stem from skid trails (metres). The logistic model was estimated for all treatments together and a *P* value of 0.1 was used as the inclusion criterion for variables in the model. A *P* value of more than 0.05 in the Hosmer and Lemeshow test indicates that logistic regression is appropriate for analyzing the data (Landau and Everitt 2004). The percentages of damage were combined into three classes, viz. no damage, 1–2 % of trees damaged, and 2–4 % of trees damaged.

Results

Amount of Tree Damage

The statistical analysis indicates that the mean number of trees per hectare before logging operation did not differ between the three treatments (ANCOVA; $F_{1,5} = 2.01$, $P_{\text{value}} = 0.495$). Most of the basal area removed in each treatment was from beech and alder trees. These species accounted for 87 % of the basal area removed in the first d, 79 % removed in the second treatment, and 89 % removed in the third treatment as a weighted mean. Of the 489 residual trees near the skid trails, 339 (69 %) received some damage. Wound sizes on roots and butts were significantly larger under more intensive logging than under medium or low intensity logging (ANOVA; $F_{2,\ 6} = 80.22$, $P_{\text{value}} = 0.000$), but the wound–stem ratio does not differ significantly among treatments ($F_{2,\ 6} = 1.\ 10$, $P_{\text{value}} = 0.\ 391$) (Fig. 2).

The average size of scuffs, scrapes and gouges was significantly larger in the high intensity treatment (Treatment 3) than in the low and medium intensity treatment (Table 3). The wound–stem ratio of scrapes was similar among treatments ($P_{\text{value}} = 0.315$), but the wound–stem ratios of scuffs and gouges were larger in the high intensity treatment than in the other treatments (Table 3). In the study area, the distance of damaged trees from the edge of skid trails was measured, which

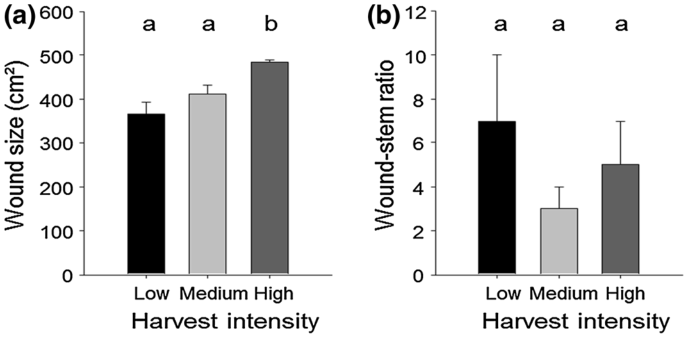

Fig. 2 Mean wound size (**a**) and wound–stem ratio (**b**) (including standard error) on roots and butts for all trees of diameter 10 cm or more. *Note Identical letters* indicate no significant differences among treatments, by ANOVA and the Duncan multiple comparisons test

Table 3 Mean wound size and wound–stem ratio (standard error) on the roots and butts for all trees 10 cm and more in diameter, classified by cause and type of wound

Treatment	N	Wound size (cm^2)			Wound–stem ratio		
		Scuff	Scrape	Gouge	Scuff	Scrape	Gouge
1 (low intensity)	3	85 (3.5)[a]	348 (15.3)[a]	38 (1.7)[a]	6.3 (0.45)[a]	10.5 (0.35)[a]	3.8 (0.39)[a]
2 (medium intensity)	3	98 (1.2)[b]	378 (13.0)[a]	57 (4.4)[b]	5.6 (0.22)[a]	11.3 (0.56)[a]	2.8 (0.38)[a]
3 (high intensity)	3	118 (2.5)[c]	475 (4.91)[b]	67 (2.4)[b]	8.2 (0.03)[b]	11.8 (0.70)[a]	5.8 (0.07)[b]
P value		0.000	0.001	0.001	0.002	0.315	0.001

Identical letters indicate no significant differences among treatments (ANOVA and Duncan multiple comparison of means)

varied from 0 to 2 m. About 97 % of scuffs, scrapes and gouges occurred within the first 1.3 m of the stem, over all treatments.

Damage Probability

Regardless of treatment, two variables were found to be significant in predicting the probability that an individual tree will be damaged, namely cross slope of skid trail ($F_{4,\,24} = 218.33$, $P_{\text{value}} < 0.001$) and distance from skid trail edge ($F_{3,\,24} = 174.64$, $P < 0.001$). In order to assess the individual effects of the three treatments, each treatment was tested as a baseline against the other two; for example the effect of low harvest intensity was compared to medium and high harvest intensity. The high intensity treatment effects are significantly different from low and medium treatment effects with respect to cross slope of skid trail and distance of trees from skid trail edge ($F_{2,24} = 5.87$, $P_{\text{value}} < 0.01$). The ratios indicate that a tree in the high intensity treatment is 2.6 times as likely to be damaged compared to one in the low intensity treatment. The final probability model resulted in three different intercept parameters (one for each treatment):

$$b_{01} = 0.4213,\ b_{02} = 0.6712,\ b_{03} = 1.0923$$

The final model is described as:

$$P\ (\text{damage}) = [1 + \exp(-(b_0 + 0.0112(\text{SLOP}) - 0.0377(\text{DIST}))] - 1$$

where P (damage) is the probability of tree damage, SLOP is the slope intercept for skid trails, and DIST is the distance of an individual stem to the nearest skid trail.

The magnitudes of the b values explain the form of regression equations depending on harvest intensity. Land slope and distance from skid trail as independent variables had a significant effect on the probability of damage across all treatments. In all treatments, as land slope increases, the probability of damage increased, and as distance from the skid trail increases, the probability of damage decreases. Overall, the probability of damage is higher for high intensity logging than for low and medium intensity logging. The value of the slope variable (average ground slope in three skidding treatments) ranged from 5 to 18 % in high and 2–12 % in low and medium intensity harvesting. It is to be noted that the longitudinal average slope of skid trails in the study area is 19 %. For distances from skid trail (0–2 m) the probability of damage ranged from 35 to 77 % for marginal residual trees in high intensity treatments and 26–67 % for marginal residual trees in low and medium intensity treatments.

Discussion

When using selective logging in mixed stands of the Caspian forests, the log injury rate is influenced by harvest intensity. Decreasing harvest intensity will primarily reduce the probability of damaging trees or reducing tree mortality. In contrast with high and low harvest intensity, benefits of medium harvest intensity may also include better growth and regeneration of commercial species without additional silvicultural intervention because there is of a positive response of seedling establishment with increasing harvest intensity up to a medium level due to wider tree spacing.

Other studies have proved that wounds with more than 100 cm^2 of exposed sapwood are likely to lead to decay of wood and result in volume-degradation up to 20 years after injury (Lavallee and Lortie 1968). Moreover, wounds of 254 cm^2 or more are less likely to close 10 years after occurring compared to smaller wounds (Smith et al. 1994). In this study, increasing the harvest intensity resulted in a higher frequency of damage to residual trees and larger wound sizes. Logically, the risk of injury would be highest where the probability of contact with the residual stand is highest. The injury rate probably should rise proportionally with the amount of log movement or handling in the stand. The highest injury rates were found closest to the skid trail. Studies in other countries using damage probability models generated similar results regarding the distance from the skid trail (e.g. Nichols et al. 1994). This is because most log handling occurs on the skid trail. Nichols et al. (1994) also reported that as pre-harvest basal area of the stand increased, the probability of damage increased. This result is similar to the results of the present study.

Conclusion

For two decades, researchers and specialists have advised using selective logging in the Caspian forests of Iran because this management approach reduces the negative environmental impacts. Silvicultural practices have traditionally been designed to maximize revenue gained from forests and increase timber volume harvested. During the last two decades, demands focused on minimizing the adverse impacts of harvesting. Despite the benign reputation of selection logging, no previous study has quantified the effect of harvest intensity on residual trees in Caspian forests. The results of present study reveal that the greatest risk of injury occurs at high harvest intensity.

Although the damage resulting from skidding operations increase with increasing harvest intensity, a medium level may be beneficial for moving toward sustainable forest management. Harvest intensity at a medium level would minimize the occurrence of adverse impacts caused by wood harvesting and extraction machines on the forest ecosystem. Also limiting the harvest intensity to 5 trees/ha (medium harvest intensity) or less will limit harvest damage.

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